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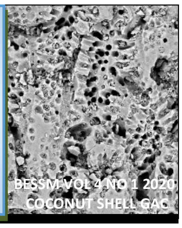

Modelling the Growth of Nile Tilapia (*Oreochromis niloticus*) on Fed Diets Formulated from Local Ingredients in Cages

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ABSTRACT

The use of agricultural by-products as a fish meal is an attempt to minimize the cost of fish production to aquaculturist and to also create a more environmentally friendly practice. Due to high demand of Tilapia fish, efforts to improve its growth performance is highly needed. The application of linearization technique by natural logarithm transformation, even though standard, is inaccurate and can just provide an estimated value for the single parameter measured; the specific growth rate. In this paper, for the first time we used various kinetics models such as Von Bertalanffy, Baranyi-Roberts, modified Schnute, modified Richards, modified Gompertz, modified Logistics and most recent Huang were used to get values for the above constants or parameters from Nile Tilapia *Oreochromis niloticus* growth on fed diets formulated from local ingredients in cages. At the end of the modelling exercise, Baranyi-Roberts model proved to be the finest model with the highest adjusted R^2 value and lowest RMSE value. The Accuracy and Bias Factors values were close to unity (1.0). The kinetics modelling shows that the most satisfactory fitting is with the Baranyi-Roberts model. The use of Nile Tilapia growth models to obtained exact growth rate is advantageous for further development of secondary model and this work has revealed the capability of such models.

INTRODUCTION

The usage of on-farm materials like agricultural by-products for improved fish culture is a cheapest way of improving rural aquaculture in different low income nations and one of the major challenge to this is inadequate supply of less expensive and nutritive fish feed [1]. Fish meal has locally been used as the source of protein for formulated fish feed because of its good protein content, required amino acid profile, highly digestible as well as palatable, it also serve as a source of essential n-3 polyenoic fatty acids [2,3]. However, the inadequate supply of global fish meal, that is the major conventional source of protein together with its high request in livestock and poultry industry is expected to decrease the over reliance on it as a single protein source in aquafeeds [3–5]. Fishmeal is also reported to be highly expensive over a period of time [6].

Tilapia culture is expanding in many regions of the world [7]. Growth in the global tilapia culture and the continuous intensification of the culture systems have resulted in a constant search for strains with superior growth performance [8,9]. Studies of growth curves in tilapias have been very vital by using equations that can predict the weight of the animal based on its age, since they summarize information from a data series into a small set of bio-logically interpretable parameters [10]. The growth curve is in sigmoidal form, representing the behaviour of body weight, length, or height in relation to the age of the animal under study [11]. Growth at the early stage of life is slow, followed by a period of self-acceleration, until the point of maximum growth rate is attained, close to puberty, when there is an auto-slowdown phase [12].

Nonlinear applications used to model the age–weight relationship to describe the growth curve, traditionally including

Brody, Richards, Von Bertalanffy, Gompertz, and Logistic growth functions [8,10,13–16]. Nonlinear equations present various biological understanding associated to initial conditions, growth rate, or body weight, all related to economic aspects of fish farming [17]. The equations that were used in various studies of different fish species such as Dourada [18], Atlantic blue marlin, Blacktip shark, Tautog, Atlantic spadefish, Yellowtail, Redear sunfish [19] and Tambaqui [17]. The use of nonlinear models for the adjustment of growth curves in tilapia fish was reported to be satisfactory using all these models Brody, Von Bertalanffy, Logistic, Gompertz and Richards [10]. Nevertheless, the Gompertz and Von Bertalanffy models were the most suitable for strains of tilapia [20]. Gompertz model is reported to be more suitable in adjusting the growth curve of fish, this due to the fact that, the body weight at early age is always more than zero [18,21], it can also provide a good fit even if there is changes in fish growth until the fish reaches maturity stage [22].

Contrarily, the growth curve of bacteria indicated a sigmoidal pattern, it begins with the lag section just after t = 0, followed by the logarithmic section and then the bacteria move in to stationary phase and lastly moves to death phase or reduction in bacterial growth. To describe the bacterial growth curve, different sigmoidal functions like Von Bertalanffy, Baranyi-Roberts, modified Schnute, modified Richards, modified Gompertz, modified Logistics and stannard were compared [23]. They were statistically compared by a comprehensive model (Schnute model), which is a model that comprises all other models. The F test and the t test were applied. In the F test, the lack of fit of the models is compared with the measuring error while in the t test, confidence intervals for parameters can be assessed and can be used to differentiate between the models. Moreover, the models were compared with respect to their easy practice. To hold all biologically related parameters, all sigmoidal functions were modified. The models of Stannard, Schnute and Richards seemed to be fundamentally the same equation [24,25]. In the cases verified, the modified Gompertz equation was statistically sufficient to explain the growth data. The growth curve valued parameters are the maximum specific growth rate (μ_{max}), the lag period and the asymptotic values. The maximum specific growth rate (μ_{max}) value can be used in the development of secondary models to evaluate the effects of substrate, temperature, pH and product on bacterial growth rate. In other studies, mathematical modelling of Mo-blue production have been carried out [26,27] but all these studies use the linearization of the Mo-blue production over time profile to get the specific growth rate for further secondary modelling. Due to the usefulness of nonlinear regression analysis on the growth of different organisms as described above, thus, the objective of this work is to evaluate different models like Logistic [23,28], Gompertz [23,29], modified Richards [23,30], Schnute [23], Baranyi-Roberts [25], Von Bertalanffy [31,32], Buchanan three-phase [24] and more recently Huang model [33]. In this study, we show for the first time the applicability of the different models in modelling the growth of Nile tilapia (*Oreochromis niloticus*) on fed diets formulated from local ingredients in cages.

MATERIALS AND METHODS

Data in Fig 2a. from Ngugi et al. [34] was processed by the software Webplotdigitizer 2.5 [35] that digitizes the scanned figure that has been utilized by various investigators and acknowledged for its consistency [36,37].

Statistical analysis

The statistically significant difference between the models was calculated using different methods including the adjusted determination coefficient (R2), accuracy factor (AF), bias factor (BF), root-mean - square error (RMSE) and AICc (Akaike Information Criterion) corrected as before. [36].

Fitting of the data

Using the CurveExpert Professional software (Version 1.6), nonlinear regression using the Marquardt algorithm was performed to fit the bacterial growth curve using various growth models (Table 1). The μmax of the estimation was performed by the steepest ascent rifle of the curve, whereas the x-axis crossing of this line is an estimate of λ. The model that shows a high growth was adopted for the purpose of modelling.

Table 1. Growth models used in modelling the growth curve of Nile tilapia.

Model	p	Equation
Modified Logistic	3	$y=\frac{A}{\left\{1+\exp\left[\frac{4\mu_m}{A}(\lambda-t)+2\right]\right\}}$
Modified Gompertz	3	$y=A\exp\left\{-\exp\left[\frac{\mu_m e}{A}(\lambda-t)+1\right]\right\}$
Modified Richards	4	$y=A\left\{1+v\exp(1+v)\exp\left[\frac{\mu_m}{A}(1+v)\left(1+\frac{1}{v}\right)(\lambda-t)\right]\right\}^{\left(\frac{-1}{v}\right)}$
Modified Schnute	4	$y=\left(\mu_m\frac{(1-\beta)}{\alpha}\right)\left[\frac{1-\beta\exp(\alpha\lambda+1-\beta-\alpha t)}{1-\beta}\right]^{\frac{1}{\beta}}$
Baranyi-Roberts	4	$y=A+\mu_m x+\frac{1}{\mu_m}\ln\left(e^{-\mu_m x}+e^{-h_0}-e^{-\mu_m x-h_0}\right)$ $-\ln\left(1+\frac{e^{\mu_m x+\frac{1}{\mu_m}\ln\left(e^{-\mu_m x}+e^{-h_0}-e^{-\mu_m x-h_0}\right)}-1}{e^{(y_{\max}-A)}}\right)$
Von Bertalanffy	3	$y=K\left[1-\left[1-\left(\frac{A}{K}\right)^3\right]\exp^{-\left(\mu_m x/3K^{\frac{1}{3}}\right)}\right]^3$
Huang	4	$y=A+y_{\max}-\ln\left(e^A+\left(e^{Y_{\max}}-e^A\right)e^{-\mu_m B(x)}\right)$ $B(x)=x+\frac{1}{\alpha}\ln\frac{1+e^{-\alpha(x-\lambda)}}{1+e^{\alpha\lambda}}$
Buchanan Three-phase linear model	3	Y = A, IF X < LAG Y=A + K(X−λ), IF λ ≤ X ≥ X_{MAX} Y = Y_{MAX}, IF X ≥ X_{MAX}

Note:
A= Nile tilapia growth lower asymptote;
y_{max}= Nile tilapia growth upper asymptote;
m_{max}= maximum specific Nile tilapia growth rate;
v= affects near which asymptote maximum growth occurs.
l=lag time
e = exponent (2.718281828)
t = sampling time
a,b, k = curve fitting parameters
h_0 = a dimensionless parameter quantifying the initial physiological state of the reduction process. The lag time (h^{-1}) or (d^{-1}) can be calculated as h_0=m_{max}

RESULTS AND DISCUSSION

All of the curves tested display visually satisfactory fitting (**Figs 2** to **9**). The growth data of Nile tilapia need to be transformed to log unit prior to modelling. The finest growth was found using the Baranyi-Roberts model with the least value for RMSE, AICc and the uppermost value for adjusted R^2. The AF and BF values were seen to be excellent for the model and their values were the nearer to 1.0. The least performance was the modified Richard model (**Table 2**). The coefficients for the Baranyi-Roberts model are shown in **Table 3**.

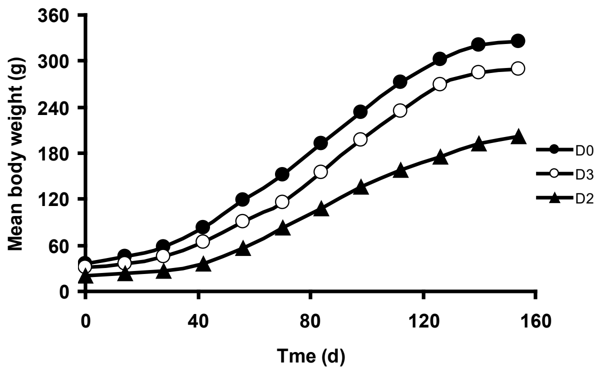

Fig 1. Replotted data on growth of Nile tilapia on various diets.

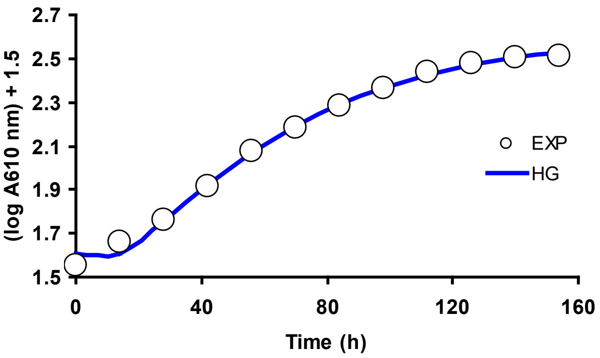

Fig. 2. Growth of Nile tilapia as modelled using the Huang model

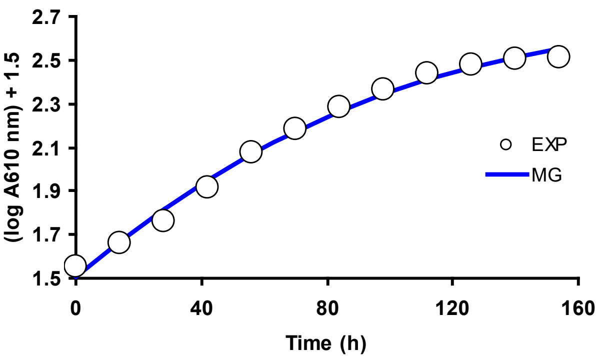

Fig. 3. Growth of Nile tilapia as modelled using the modified Gompertz model.

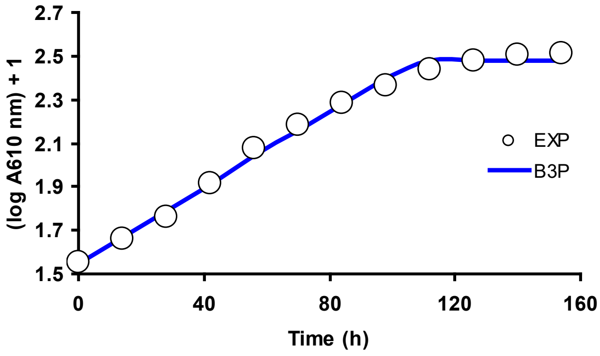

Fig. 4. Growth of Nile tilapia as modelled using the Buchanan-3-phase model.

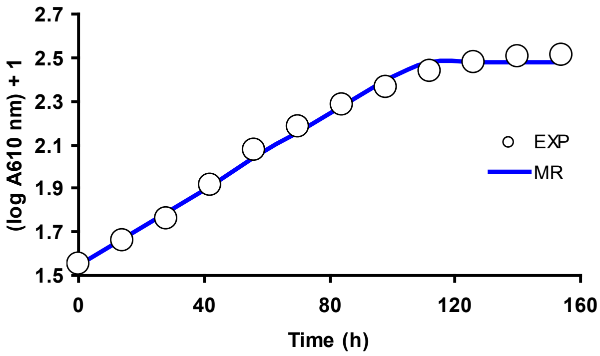

Fig. 5. Growth of Nile tilapia as modelled using the modified Richard model.

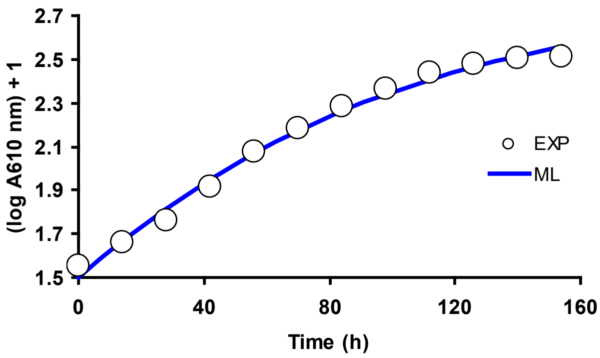

Fig. 6. Growth of Nile tilapia as modelled using the modified Logistics model.

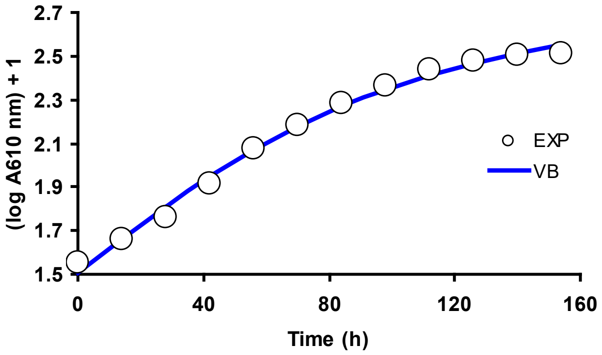

Fig. 7. Growth of Nile tilapia as modelled using the von Bertalanffy model.

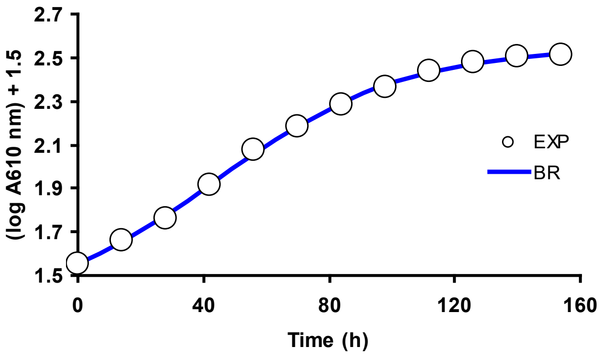

Fig. 8. Growth of Nile tilapia as modelled using the Baranyi-Roberts model.

Table 2. Statistical tests for the various models utilized in modelling the growth curve of Nile tilapia.

Model	*p*	RMSE	R^2	adR^2	AF	BF	AICc
Huang	4	0.028	0.995	0.992	1.008	1.000	-62.33
Baranyi-Roberts	4	0.010	0.999	0.999	1.003	1.000	-86.49
modified Gompertz	3	0.035	0.992	0.989	1.010	1.000	-64.46
Buchanan-3-phase	3	0.029	0.994	0.992	1.010	1.000	-68.71
modified Richards	4	0.039	0.991	0.986	1.013	1.000	-54.96
modified Schnute	3	0.014	0.999	0.998	1.004	1.000	-79.31
modified Logistics	3	0.030	0.994	0.991	1.011	1.000	-67.64
von Bertalanffy	4	0.036	0.991	0.988	1.013	1.000	-63.46

Note: p is no of parameter

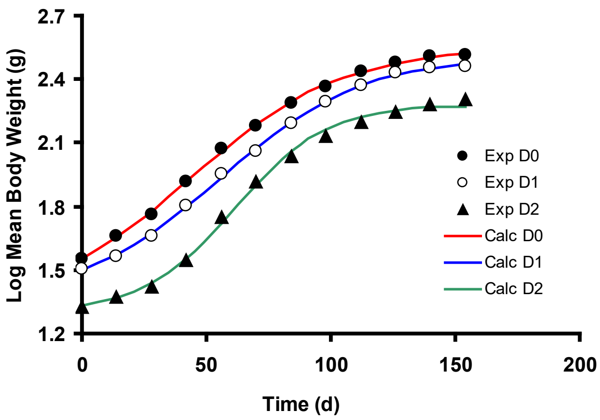

Fig 9. Modelling of the log growth of Nile tilapia on various diets using the Baranyi-Roberts model.

Table 3. Growth coefficients as modelled using the Baranyi-Roberts model.

Parameters	Value	95% Confidence interval
D0		
Initial growth value	35.56	33.88 to 37.33
Final growth value	352.37	331.89 to 74.97
Specific growth rate	0.03	0.03 to 0.04
D2		
Initial growth value	31.33	29.6483 to 33.11
Final growth value	319.15	296.483 to 343.56
Specific growth rate	0.04	0.031 to 0.04
D1		
Initial growth value	20.56	18.88 to 22.39
Final growth value	199.07	182.81 to 216.77
Specific growth rate	0.05	0.039 to 0.06

The overlapping of the 95% confidence intervals for the specific growth rate (SGR) parameter indicate no significant differences [38,39] while there is an overlap between feeds D0 and D2 for the final growth value indicating no significant difference in terms of performance whilst for D1 the final growth value was significantly the lowest among the three diets (**Table 3**).

The Baranyi-Roberts model was firstly introduced by Baranyi [25], and has found to be used in the modelling of many microorganism growth but mainly bacteria [25,40–50]. In addition, the Baranyi-Roberts model has been effectively applied to model algae growth as documented in various works [51,52]. Growth of some fish is also best described by this model [41,53]. The Baranyi-Roberts model was recommended to generally be a lot more automatic in qualities than the modified Gompertz model, having its parameters with a biological meaning in comparison to the modified Gompertz model. This is attributed to the fact that, the model is having 4 parameters to be fitted. Another important approach to improve the statistical benefit of a mechanistic model having four parameter against a non-mechanistic three-parameter model is basically to upsurge the number of sets of data acquired [23].

The obtained parameters from the fitting activities were maximum fish growth rate (m_m), lag time (l) the dimensionless parameter h_o and maximal fish growth (Y_{max}). The three biologically meaningful coefficients (m_m), lag time (l) and maximal fish growth (Y_{max}) would be later applied for secondary modelling of fish growth. These mechanistic models are applied in basic research and are meant to attain a better understanding of the physical, chemical and biological processes that causes to the growth profile observed. Under normal circumstance, the mechanistic models are more reliable because they inform about the fundamental processes driving patterns. They are expected to work appropriately when extrapolating beyond the experimental conditions [54].

CONCLUSION

In conclusion, The Baranyi-Roberts model was the best model in modelling the growth of Nile tilapia (*Oreochromis niloticus*) on fed diets formulated from local ingredients in cages based on statistical tests such as corrected AICc (Akaike Information Criterion), bias factor (BF), adjusted coefficient of determination (R^2) and root-mean-square error (RMSE). Parameters obtained from the fitting exercise were maximum growth rate (μ_{max}), lag time (l), maximal growth (Y_{max}) and minimal growth (Y_o). The use of Nile Tilapia growth models to obtained exact growth rate is advantageous for further development of secondary model and this work has revealed the capability of such models.

REFERENCES

1. Ngugi CC, Egna H, Oyoo-okoth E, Manyala JO. Growth, yields and economic benefit of Nile tilapia (*Oreochromis niloticus*) fed diets formulated from local ingredients in cages Growth , yields and economic benefit of Nile tilapia (*Oreochromis niloticus*) fed diets formulated from local ingredients i. Int J Fish Aquat Stud. 2016;4(1).
2. Hardy R, Tacon A. Fish meal: historical uses, production trends and future outlook for sustainable supplies. In: Stickney, RR and McVey, JP (ed), Responsible marine aquaculture CABI Publishing, Wallingford, UK. 2002. p. 311–25.
3. Jackson A. The importance of fishmeal and fish oil in aquaculture diets. Int Aquafeed. 2006;9:16–9.
4. El-Saidy D, Gaber MMA. Replacement of fish meal with a mixture of different plant protein sources in juvenile Nile tilapia *Oreochromis niloticus* (L.) diets. Aquac Res. 2003;34:1119–27.
5. Ytrestøyl T, Synnøve T, Åsgård T. Utilization of feed resources in production of Atlantic salmon (*Salmo salar*) in Norway. Aquaculture. 2015;448:365–74.
6. IFFO. International Fishmeal and Fish Oil Organization. (2008). IFFO Update, 2008; 187:11. 2008.
7. PeixeBR. Brazilian Association of Pisciculture:Yearbook of Pisciculture. 2018.
8. Costa AC, Neto RR, Freitas RTF, Freato TA, Lago AA, Santos VB. Avaliação do crescimento de tilápias de diferentes linhagens através de modelos não lineares. Arch Zootec. 2009;58(1):561–4.
9. de Assis Lago A, Teruel T, Aurélio M, Dias D, Tadeu R, Freitas F De, et al. The development of genetically improved red tilapia lines through the backcross breeding of two *Oreochromis niloticus* strains. Aquaculture. 2017;472(2017):17–22.
10. dos Santos VB, Fonseca de Freitas, R. T. Fonseca e Silva F, Freato TA. Evaluation of morhometric growth curves of tilapia of Nilo (*Oreochromis niloticus*) strains. Ciênc E Agrotecnologia. 2007;31(5):1486–92.
11. Fitzhugh Jr H. ANALYSIS OF GROWTH CURVES AND STRATEGIES FOR ALTERING THEIR SHAPE. J Anim Sci. 1976;42(4):1036–51.
12. Berg RT, Butterfield RM. New concepts of cattle growth. Sydney University Press, University of Sydney.; 1976.
13. Loaiza-echeverri AM, Bergmann JAG, Toral FLB, Osorio JP, Carmo AS, Mendonça LF, et al. Theriogenology Use of nonlinear models for describing scrotal circumference growth in Guzerat bulls raised under grazing conditions. Theriogenology. 2013;79(5):751–9.
14. Mayra A, Zardin O, Antonio C, Oliveira L De, Nogueira S, Oliveira D, et al. Growth curves by Gompertz nonlinear regression model for male and female Nile tilapias from di ff erent genetic groups. Aquaculture. 2019;511(June 2018):734243.
15. Mazzini AR DE, Muniz JA, DE Aquino LH, Silva FFE. Growth curve analysis for hereford cattle males. Ciênc E Agrotecnologia. 2003;27(5):1105–12.
16. Oliveira da SAM, de Oliveira CAL, Matsubara BJA, de Oliveira SN, Kunita NM, Yoshida GM, et al. Growth patterns of male and female of Nile tilapia (*Oreochromis niloticus*) GIFT variety. Semina Ciênc Agrár. 2013;34(4):1891–9.
17. Mello F De, Oliveira CAL, Ribeiro RP, Resende EK. Growth curve by Gompertz nonlinear regression model in female and males in tambaqui (Colossoma macropomum). An Acad Bras Ciênc. 2015;87(2015):2309–15.
18. Gamito S. Growth models and their use in ecological modelling : an application to a fish population. Ecol Model. 1998;113:83–94.
19. Hernandez-llamas A, Ratkowsky DA. Growth of fishes, crustaceans and molluscs: estimation of the von Bertalanffy, Logistic, Gompertz and Richards curves and a new growth model. Mar Ecol Prog Ser. 2004;282(16):237–44.
20. Sousa Júnior JDAD, Garrido MDS, de Carvalho PG, Rocha LGD, Campeche DF. Mathematical modelling Applied To The Growth Of Tilapia In Net Cages In The Sub Middle Of The São Francisco River. Eng Agríc. 2014;34(5):1001–11.
21. Fialho B. Interpretação da curva de crescimento de Gompertz. Concórdia. Embrapa-CNPSA. 1999.
22. Vander B dos S, Edson AM, Maeli DPS. Growth curves of Nile tilapia (*Oreochromis niloticus*) strains cultivated at different temperatures. Acta Sci Anim Sci. 2013;35(3):235–42.
23. Zwietering MH, Jongenburger I, Rombouts FM, Van't Riet K. Modeling of the bacterial growth curve. Appl Environ Microbiol. 1990;56(6):1875–81.
24. Buchanan RL. Predictive food microbiology. Trends Food Sci Technol. 1993;4(1):6–11.
25. Baranyi J. Mathematics of predictive food microbiology. Int J Food Microbiol. 1995;26(2):199–218.
26. Othman AR, Bakar NA, Halmi MIE, Johari WLW, Ahmad SA, Jirangon H, et al. Kinetics of molybdenum reduction to molybdenum blue by *Bacillus* sp. strain A.rzi. BioMed Res Int. 2013 Jan;2013:1–9.
27. Halmi MIE, Shukor MS, Wan Johari WL, Shukor MY. Mathematical Modeling of the Growth Kinetics of *Bacillus* sp. on Tannery Effluent Containing Chromate. J Environ Bioremediation Toxicol. 2014;2(1):6–10.
28. Ricker WE. 11 Growth Rates and Models. 1979. 677 p. (Fish Physiology; vol. 8).
29. Gompertz B. On the nature of the function expressiveness of the law of human mortality, and a new mode of determining the value of life contingencies. Philos TransR Soc Lond. 1825;115:513 – 585.
30. Richards FJ. A flexible growth function for empirical use. J Exp Bot. 1959;10:290–300.
31. Babák L, Šupinová P, Burdychová R. Growth models of Thermus aquaticus and Thermus scotoductus. Acta Univ Agric Silvic Mendel Brun. 2012;60(5):19–26.
32. López S, Prieto M, Dijkstra J, Dhanoa MS, France J. Statistical evaluation of mathematical models for microbial growth. Int J Food Microbiol. 2004;96(3):289–300.
33. Huang L. Optimization of a new mathematical model for bacterial growth. Food Control. 2013;32(1):283–8.
34. Ngugi C, Egna H, Oyoo-Okoth E, Manyala J. Growth, yields and economic benefit of Nile tilapia (*Oreochromis niloticus*) fed diets formulated from local ingredients in cages. Int J Fish Aquat Stud. 2016 4(6): 191-195
35. Rohatgi.A..WebPlotDigitizer. http://arohatgi.info/WebPlotDigitizer/app/ Accessed June 2 2014.; 2015.
36. Halmi MIE, Shukor MS, Johari WLW, Shukor MY. Modeling the growth curves of *Acinetobacter* sp. strain DRY12 grown on diesel. J Environ Bioremediation Toxicol. 2014;2(1):33–7.
37. Khare KS, Phelan Jr FR. Quantitative comparison of atomistic simulations with experiment for a cross-linked epoxy: A specific volume–cooling rate analysis. Macromolecules. 2018;51(2):564–575.
38. Wijtzes T, Veld JHJ, t van, Zwietering M. Modelling bacterial growth of *Lactobacillus curvatus* as a function of acidity and temperature. Appl Environ Microbiol 61 1995 2533-2539. 1995 Jan;61.
39. Schenker N, Gentleman JF. On judging the significance of differences by examining the overlap between confidence intervals. Am Stat. 2001;55(3):182–6.
40. Baranyi J, Roberts TA, Mcclure P. Some properties of a nonautonomous deterministic growth model describing the adjustment of the bacterial population to a new environment. Math Med Biol. 1993;10(4):293–9.
41. Dalgaard P. Modelling of microbial activity and prediction of shelf life for packed fresh fish. Int J Food Microbiol. 1995;26(3):305–17.
42. Alavi SH, Puri VM, Mohtar RH. A model for predicting the growth of listeria monocytogenes in packaged whole milk. J Food Process Eng. 2001;24(4):231–51.
43. Pin C, García de Fernando GD, Ordóez JA, Baranyi J. Analysing the lag-growth rate relationship of *Yersinia enterocolitica*. Int J Food Microbiol. 2002;73(2–3):197–201.
44. Coleman ME, Tamplin ML, Phillips JG, Marmer BS. Influence of agitation, inoculum density, pH, and strain on the growth parameters of *Escherichia coli* O157:H7 - Relevance to risk assessment. Int J Food Microbiol. 2003;83(2):147–60.
45. Shorten PR, Membré J-M, Pleasants AB, Kubaczka M, Soboleva TK. Partitioning of the variance in the growth parameters of *Erwinia carotovora* on vegetable products. Int J Food Microbiol. 2004;93(2):195–208.

46. Dominguez SA, Schaffner DW. Development and validation of a mathematical model to describe the growth of *Pseudomonas* spp. in raw poultry stored under aerobic conditions. Int J Food Microbiol. 2007;120(3):287–95.
47. Dong Q, Tu K, Guo L, Li H, Zhao Y. Response surface model for prediction of growth parameters from spores of *Clostridium sporogenes* under different experimental conditions. Food Microbiol. 2007;24(6):624–32.
48. Juneja VK, Melendres MV, Huang L, Subbiah J, Thippareddi H. Mathematical modeling of growth of Salmonella in raw ground beef under isothermal conditions from 10 to 45 °C. Int J Food Microbiol. 2009;131(2–3):106–11.
49. Wang L-L, Zhong W-J, Huang S-P, Hao S-X. Establishment of growth model of *Staphylococcus aureus* based on OD-TTD. Mod Food Sci Technol. 2014;30(4):160–4.
50. Abubakar M, Ahmad SA, Yasid NA, Rahman MFA, Alias SA, Hassan NAA, et al. Mathematical modelling of the growth of an Antarctic bacterium *Rhodococcus* sp. strain ADL36 on palm oil. In 10-3 Midori-cho, Tachikawa, Tokyo, Japan: National Institute of Polar Research (NIPR); 2018. Available from: http://id.nii.ac.jp/1291/00015259/
51. Lacerda LMCF, Queiroz MI, Furlan LT, Lauro MJ, Modenesi K, Jacob-Lopes E, et al. Improving refinery wastewater for microalgal biomass production and CO_2 biofixation: Predictive modeling and simulation. J Pet Sci Eng. 2011;78(3–4):679–86.
52. Tevatia R, Demirel Y, Blum P. Kinetic modeling of photoautotropic growth and neutral lipid accumulation in terms of ammonium concentration in *Chlamydomonas reinhardtii*. Bioresour Technol. 2012;119:419–24.
53. Yilmaz MT. Identifiability of Baranyi model and comparison with empirical models in predicting effect of essential oils on growth of *Salmonella* Typhimurium in rainbow trout stored under aerobic, modified atmosphere and vacuum packed conditions. Afr J Biotechnol. 2011;10(38):7468–79.
54. Bolker BM. Ecological Models and Data in R. Princeton, N.J: Princeton University Press; 2008. 408 p.